Distant Supernovae and the Accelerating Universe

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ABSTRACT: The observation of SN 1997ff at redshift 1.7 has been claimed to refute alternative models such as grey dust or evolution for the faintness of distant supernovae, leaving only an accelerating Universe as a viable model. However, a very simple one parameter evolution model, with the peak luminosity varying as an exponential function of cosmic time, converts the flux vs. distance law of the critical density matter-dominated model into that of the concordance $\Omega=0.3$ flat vacuum-dominated model with an error no larger than 0.03 mag over the range 0-2 in redshift. A grey dust model that matches this accuracy can easily be contrived but it still fails by overproducing the far-IR background or distorting the CMB. Models that involve oscillation between photons and axions could emulate an exponential function of cosmic time without violating these background constraints. Clearly a better and well-tested understanding of the Type Ia supernova explosion mechanism and the origin of the correlation between the decay rate and luminosity is needed before any effort to reduce statistical errors in the supernova Hubble diagram to very small levels.

The observations of Type Ia SNe are only determining the luminosity distance vs. redshift law, $D_L(z; P)$, where P is a set of cosmological parameters, typically Ω_M and Ω_{Λ} . Obviously if the intercept of the supernova luminosity vs decay rate relation evolves² following the relation

$$L(z) = (D_L(z; P')/D_L(z; P))^2$$
(1)

then the true cosmological parameters would be P' even though $D_L(z; P)$ fits the data well under the assumption of no evolution. If I evaluate Eqn(1) with $P' = \{\Omega_M = 1, \Omega_{\Lambda} = 0\}$ being the Einstein - de Sitter critical density matter dominated model and $P = \{\Omega_M = 0.3, \Omega_{\Lambda} = 0.7\}$ being the concordance model, then Figure 1 is obtained.

This required luminosity evolution is monotonic, which contradicts the claim that evolution would have to reverse itself to match the accelerating now but decelerating in the past pattern of the concordance model. Furthermore, if I plot the required evolution on a log-linear plot as a function of cosmic time, I get the very nearly straight solid line on Figure 2. Obviously an exponential function of cosmic time [the dashed line] provides a nearly exact match to the required evolution.

Figure 3 shows various models including the exponential function of cosmic time evolution model compared to supernova data^{1,3}. Clearly both the concordance model and the exponential evolution model fit the data very well – actually too well – with χ^2 per degree of freedom much less than 1. The best fit Ω_{Λ} is 0.73 with $\chi^2 = 1.46$ for 8 df. The evolution model is a slightly better fit, with $\chi^2 = 1.24$ for 8 df at $\alpha = 1.28$. This evolution model is equivalent to the axion model in Eq(2) below with $\beta = 0$ & F = 0.

Given that the required evolution is monotonic, there is no difficulty in producing this effect using grey dust. One need only make the physical dust density constant to give the

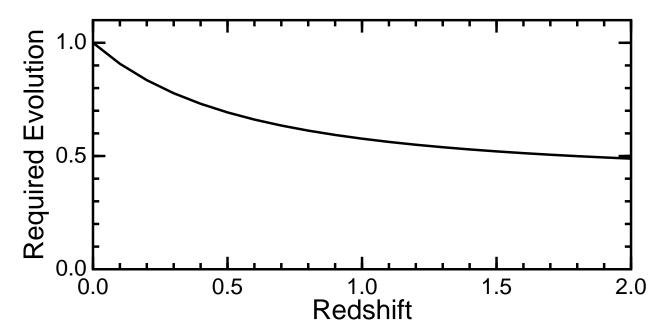


Fig. 1.— The evolution required to make an $\Omega_M=1$ model look like an $\Omega_M=0.3, \Omega_{\Lambda}=0.7$ model in the supernova Hubble diagram.

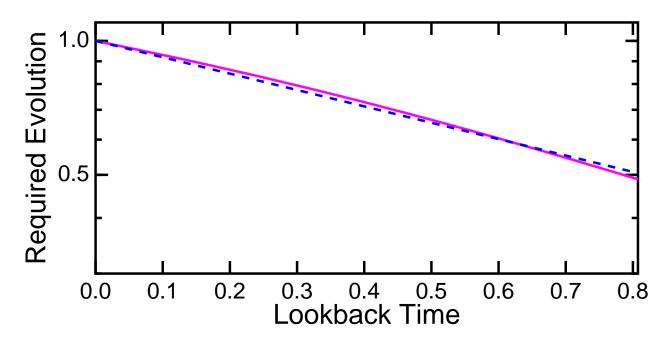


Fig. 2.— The evolution required to make an $\Omega_M = 1$ model look like an $\Omega_M = 0.3$, $\Omega_{\Lambda} = 0.7$ model in the supernova Hubble diagram. The dashed line is an exponential function of cosmic time.

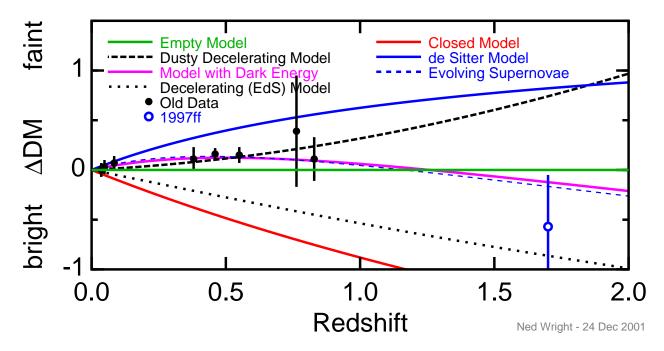


Fig. 3.— The Type Ia SNe data plotted relative to an empty Universe Milne model. The exponential evolution matches the concordance model to ≤ 0.028 mag for all $z \in [0, 2]$. The "dusty decelerating model" has a constant comoving dust density. A dust model with a constant physical dust density matches the exponential evolution.

appearance of an exponential function of cosmic time evolution model. Then the comoving dust density must vary like $(1+z)^{-3}$ which is certainly possible although it has no obvious connection to the evolution of the star formation rate [the Madau curve].

Models where light – but not millimeter waves – can oscillate into axions⁴ and thus lead to fainter distant supernovae, can also fit the data well. But the standard 1 axion asymptote with 2/3 of the light surviving is not enough dimming of the distant supernovae if the true model is an EdS Universe with $\Omega_M = 1$. Letting the observed flux vary like

Flux =
$$\frac{L}{4\pi D_I^2} [(1-F) \exp(-\alpha H_{\circ} \int_0^z (1+z)^{\beta} dt) + F]$$
 (2)

one gets a best fit in an EdS Universe of $\chi^2 = 3.99$ with $\alpha = 7$ if F is fixed at 2/3 and β is fixed at 1. But with α , β and F all free, the best fit occurs when $\alpha = 2.61$, F = 0.60 and $\beta = 3.80$, giving $\chi^2 = 0.85$ with 6 df. While this modified axion model is the best fit, and the optimum F is quite close to the expected 2/3, the model introduces many new parameters and invokes at least one tooth fairy when it claims that < 0.01% of the CMB photons convert to axions while converting 40% of the optical photons.

CONCLUSIONS

- The Hubble diagram of distant Type Ia SNe is well fit by either a vacuum-dominated accelerating Universe, or by exponential function of cosmic time evolution model in an $\Omega_M = 1$ Universe.
- Both fits are better than would be expected for the quoted errors.
- Both models require that *a priori* unlikely effects be added to the standard model. The tooth fairy counts are equal.
- One should wait for confirmation of the accelerating Universe by independent means such as CMB data before committing a large amount of resources to measuring the fine details of the SNe Hubble diagram.

REFERENCES

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